A C++20 Interface for MPI 4.0

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Introduction

The message passing interface (MPI) is the standard programming model for distributed computing today. However, MPI programs written with C have to rely on the C interface, which provides no encapsulation, requires manual memory management, and prevents the use of C++ idioms and features. This work presents a modern and idiomatic header-only C++20 interface for MPI 4.0 covering the complete specification.

The interface provides
- automatic lifetime management for each MPI object
- meaningful defaults for each MPI function
- compile-time generation of MPI data types from structures and classes
- the ability to express MPI requests as futures
- continuations to describe sequential non-blocking communication

Automatic Lifetime Management

- Managed constructors take the ownership of MPI objects after instantiation
- Unmanaged constructors take in existing MPI objects and do not take ownership by default
- Copy constructor when duplication functions are provided by MPI
- Move constructor whenever possible

Usage of Modern C++ Features

- std::function for callbacks additionally enables the usage of lambdas with captures
- std::variant for arguments that take a variety of MPI objects
- std::optional for optional parameters and indeterminate results
- strongly typed enums based on MPI enums for additional type safety

Reflection and Concepts

- Automatic MPI data types for PODs through non-boost PFR [2]
- mpi::compliant concept indicates MPI mappable types (Arithmetic types, enumerations, std::complex specializations and C-Arrays, std::arrays, std::pair, std::tuple and aggregate types of compliant types)
- Sequential contiguous containers can be used for sending multiple values (i.e., std::string, std::span, std::valarray, std::vector)

Futures and Error Handling

- Requests can be std::futures supporting the concurrency support library of the C++ standard
- mpi::when_all / mpi::when_any allows joining and syncing workflows that involve forking
- Exceptions are used when MPI functions fail
- Default error codes are available through the mpi::error namespace

Performance

We measure the performance of the library and compare it to equivalent functionality implemented with the raw C interface on the mpiBench [3] benchmark. Experiments with varying message length and node count are repeated and averaged. Experiments are run on the RWTH Aachen CLAIX-2018 compute cluster. Each node is equipped with 2 Intel Xeon Platinum 8160 Skylake processors with 24 cores at 2.1 GHz. The network is provided by a high-speed ROMA Omni-Path interconnect. The nodes are exclusively reserved for the benchmarks to eliminate effects due to other processes.

The results are shown in the plot. Each data point represents the geometric mean over the 11 MPI operations. The slight variances in runtime can be attributed to network traffic which applies even in exclusive mode. The results of the two implementations do not show recognizable patterns that indicate a disparity in performance.

Conclusion

We have presented a modern C++ interface for MPI and demonstrated that its performance overhead is negligible in comparison to the raw C interface.

For further detail, we refer the reader to the source code, distributed under the BSD 3-Clause license, accessible at https://github.com/LLNL/mpiBench or by scanning this QR code:

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References